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Solvation controlling reaction paths and gel-formation in imide derivatives

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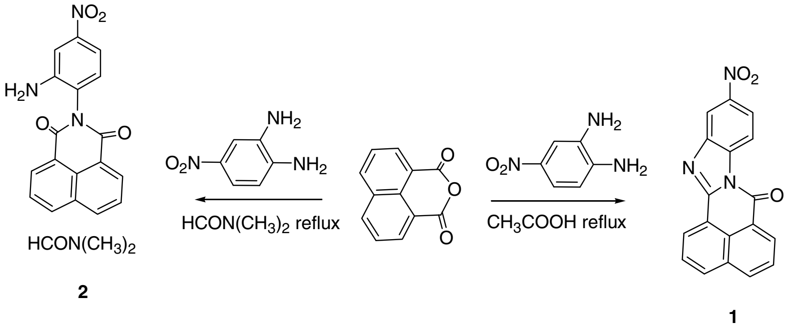
ABSTRACT

1,8-Naphthalic anhydride condenses with 4-nitro-1,2-diaminobenzene in acetic acid to give 11-nitrobenzo[*d*,*e*]benzo[2,1-*a*]isoquinoline-1,3-dione (**1**), whereas the same reaction carried out in DMF gives 2-(2-amino-4-nitrophenyl)-benzo[*d*,*e*]isoquinoline-1,3-dione (**2**). The condensation reaction of 1,8-naphthalic anhydride with 1-amino 3,5-benzene dicarboxylic acid leads to corresponding imide, which forms a gel in a mixed solvent such as water in DMSO. A similar compound 5-(1,3-dioxo-1,3-dihydroisoindol-2-yl)-isophthalic acid derived from phthalic anhydride forms gel in a mixed solvent of DMSO and water, whereas a crystalline solvate of DMSO with **2** could be obtained upon crystallization from DMSO. The crystal structure of this solvate is determined and its structure is compared with 2-(1,3-dioxo-1,3-dihydro-isoindol-2-yl)-benzoic acid. The latter does not form a gel in the mixed solvent and adopts an intermolecular hydrogen bonded structure.

Naphthalimide and phthalimide derivatives are important compounds, which possess versatile supramolecular chemistry.[1] They are also important as protecting groups for the amine functionality[2] and as optical materials, and are widely studied.[3] Due to their many applications, new synthetic methodologies for their preparation are important.[4] They are generally prepared by condensation reaction of the corresponding anhydride with primary amines; these reactions are dependent on the solvent and base used.[4] Due to the dipolar nature of the rings, these compounds bind to different solvent molecules. The phthalimide derivatives in the form of polymeric imides form gels.[5] Although there are a large number of examples in which small molecules are used as organic gelators,[6] gels from monomeric naphthalimide and phthalimide derivatives have not been reported. In this Letter, we report the role of solvent in the condensation reaction of aromatic 1,2-diamines with 1,8-naphthalic anhydride and on a new class of potentially important imide derivatives having gel-forming ability.

It is reported that reaction of 1,8-naphthalic anhydride with 1,2-diaminobenzene in acetic acid leads to heterocyclic compounds; however, this reaction in dimethylformamide is very sluggish. Whilst trying to understand this reaction, we observed that the reaction of 1,8-naphthalic anhydride with 4-nitro-1,2-diaminobenzene was dependent completely on the solvent. When the reaction was carried out in acetic acid, a heterocyclic compound 11-nitrobenzo[*d*,*e*]benzo[2,1-*a*]isoquinoline-1,3-dione (**1**) was formed, whereas in *N*,*N*-dimethylformamide, the imide derivative[7] 2-(2-amino-4-nitrophenyl)benzo[*d*,*e*]isoquinoline-1,3-dione (**2**) was obtained as illustrated in Scheme 1. The spectroscopic data



Scheme 1.

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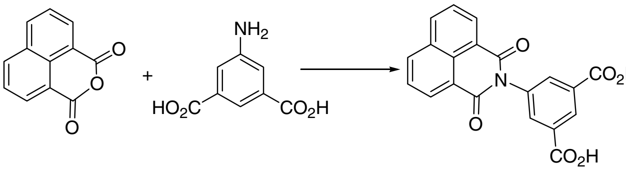
of compound **1** were compared with its earlier reported one.[8] Compound **2** was isolated as a co-crystal of *N*,*N*-dimethylformamide, the structure of which is shown in Figure 1. The co-crystals of dicarboxylic acids with DMF and DMSO are common in literature and some of them show interesting optical properties.[9]

In this co-crystal, the *N*,*N*-dimethylformamide molecules are held by strong hydrogen bonds, N3–H3a···O7 ($d_{D–H}$ 0.860 Å; $d_{D\cdots A}$, 2.858 Å; ∠D–H···A, 161.33°) and by the π–π interaction between the 1,8-naphthalimide ring with the lone pair of the nitrogen atom of the amide group. The presence of the π–π interaction is established by the distance of separation 3.35 Å. This distance is well within the admissible limit of 3.5 Å for π–π interactions. The compound shows IR absorptions for carbonyl stretching at 1771 cm^{-1} and at 1740 cm^{-1} due to the carbonyls of the *N*,*N*-dimethylformamide and the imide ring. It also demonstrates a strong absorption at 3446 cm^{-1} for the NH_2 group. The C–H group of *N*,*N*-dimethylformamide appeared at 2923 cm^{-1}, whilst the nitro group stretching was observed at 1304 cm^{-1}. In solution also DMF unit is tightly bound to the parent molecule and in the ^{1}H NMR the methyl signals appeared as two singlets at δ 2.50 and δ 2.34 ppm, whereas the hydrogen attached to the carbonyl group is significantly shielded appearing as two singlets at δ 6.45 and δ 6.42 ppm. The observation of the two singlets suggests two different environments; for the methyl groups attached to the nitrogen of dimethylformamide. Thus, the sluggish reaction in DMF as solvent is attributed to complementary hydrogen bonding ability of compound **2** with dimethylformamide.



(1)

Based on the above observation, we successfully carried out reactions of 1,8-naphthalic anhydride with 1-amino 3,5-benzene dicarboxylic acid in DMF (Eq. 1) to obtain corresponding imide (**3**). From similar reactions of 1-amino-3,5-benzene dicarboxylic acid with different cyclic anhydrides, compounds **3**–**7** listed in Table 1 were prepared. When these imides **3**–**7** were dissolved in DMSO, followed by addition of water they formed gels. A series of gels were prepared and the conditions for their formation and their properties are listed in Table 1. The T_{gel} (temperature at which the gels transforms to sol) and the critical concentration of solvents and substrates to form the gels were determined[10] and are listed in Table 1. The SEM of each gel was recorded and a representative SEM of the gel prepared from **3** is shown in Figure 2. This gel has fibre-like structure, which are of different lengths. These short thick fibre-like structures have length varying from 10 to 40 μm and width 0.5–1.0 μm. The morphology of the other gels varies and they have network structures or crystal-like structures of micron size. The gel **5** has plate-shaped structures with 2–8 μm length and 0.7–2.0 μm width. On the other hand, the gel of **6** has interconnected fibre networks with width of about 0.25–0.40 μm (please refer to Supplementary data).

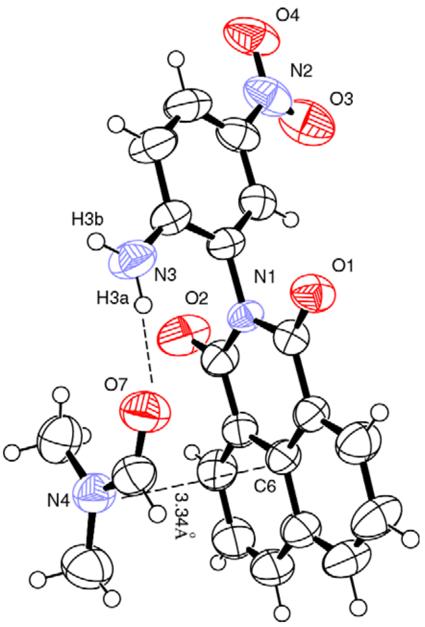
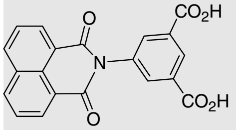
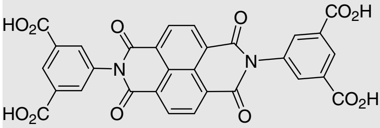
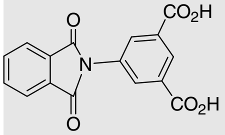
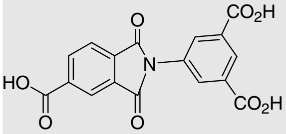
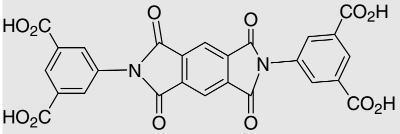


Figure 1. The crystal structure of the DMF solvate of 2-(2-amino-4-nitrophenyl)-benzo[*d*,*e*]isoquinoline-1,3-dione (50% thermal ellipsoids; CCDC No. 679218).

Table 1
Gel formation from imides

Compound	DMSO/ water	wt % (g/lit)	T_{gel} (°C)
 **3**	5:2	2.0	65
 **4**	5:2	2.77	74
 **5**	3:2	0.83	84
 **6**	3:2	1.46	68
 **7**	3:2	1.13	70

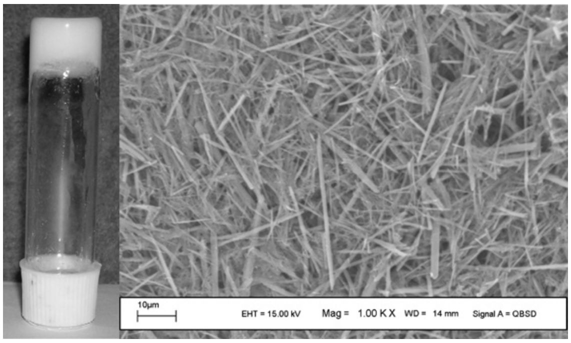
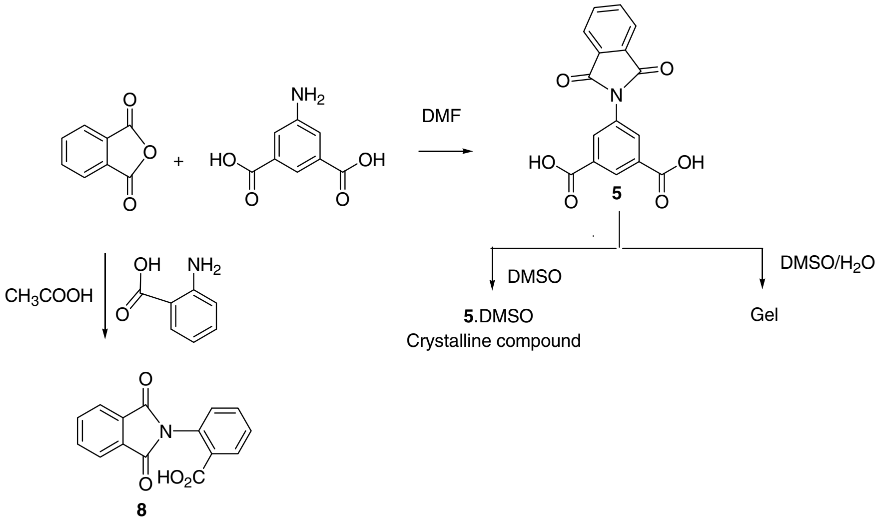


Figure 2. Left: gel prepared from **3**; right: SEM of the gel.



Scheme 2. Reactions of phthalic anhydride with aromatic amino-carboxylic acids.

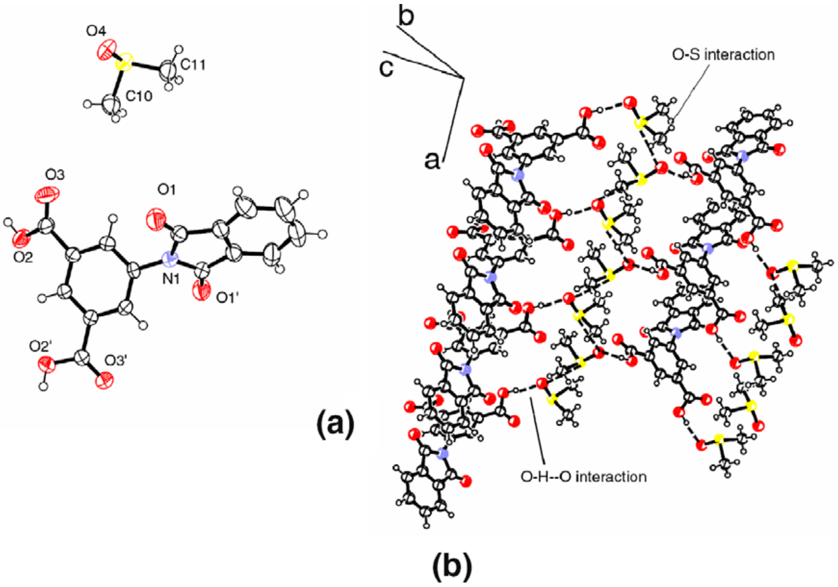


Figure 3. (a) The ORTEP diagram of **5** (CCDC No. 677168), (b) the weak interactions leading to sheet-like structures.

The 5-(1,3-dioxo-1,3-dihydro-isoindol-2-yl)-isophthalic acid (**5**) obtained from the condensation reaction of phthalimide with 1-amino-3,5-benzene dicarboxylic acid (Scheme 2) forms a co-crystal with DMSO in 1:1 ratio and was characterized by determining its crystal structure. The structure is shown in Figure 3a. Generally, carboxylic acids are strongly hydrogen bonded amongst themselves, but it is very interesting to note that the co-crystal of **5** with DMSO is devoid of O–H···O interactions amongst the carboxylic acid groups. However, it displays a hydrogen bond O2–H···O4 interaction ($d_{\text{D–H}}$ 0.818 Å; $d_{\text{D–H}\cdots\text{A}}$, 2.586 Å; ∠D–H···A, 175°) between the oxygen atom of DMSO and the OH of one of the carboxylic acid groups. This compound forms sheet-like structure in which the DMSO molecules are between the two layers of the imides. The DMSO molecules themselves have weak S···O ($d_{\text{D}\cdots\text{A}}$, 3.314 Å) interactions (Fig. 3b). The layers grow along the crystallographic *a*-axis. This arrangement leads to a highly porous structure, which, possibly on addition of water, results in a strong hydrogen bonded network leading to formation of the gel. Isophthalic acid itself forms chain-like structure by hydrogen bonding in the carboxylic acid groups.[11] 2-(1,3-Dioxo-1,3-dihydroisoindol-2-yl)-benzoic acid (**8**) does not form gel but it could be obtained in crystalline form.[12] The compound has an intermolecular hydrogen bonded structure through interaction of COOH of one molecule with carbonyl of neighbouring molecules.[12] This close-packed structure does not permit solvation, and thus it does not lead to formation of gel. Most of the compounds reported here such as **3**,[13a] **4**[13b] and **5**[13c,d] were already reported in literature; however, in this study we have shown their gel-forming abilities.

In conclusion, we have reported on the role of solvents in deciding the course of the reaction of 4-nitro-1,2-diaminobenzene with 1,8-naphthalic anhydride, and the physical state of several imide derivatives.

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2008.05.030.

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7. Preparation of 11-nitrobenzo[*d*,*e*]benzo[4,5]imidazo[2,1-*a*]isoquinolin-7-one (**1**): A mixture of 1,8-naphthalic anhydride (0.990 g, 5 mmol) and 4-nitro-1,2-diaminobenzene (0.765 g, 5 mmol) was refluxed in acetic acid (10 ml) at 90 °C for 8 h. The reaction mixture was cooled and water (20 ml) was added, and the reaction mixture was stirred for 20 min. The precipitate was filtered and washed several times with water to remove acetic acid. The product was air-dried to give 11-nitrobenzo[*d*,*e*]benzo[4,5]imidazo[2,1-*a*]isoquinolin-7-one in 77% yield. Elemental Anal. Calcd for $C_{19}H_9N_3O_3$: C, 68.57; H, 2.88. Found: C, 68.62; H, 2.86. ^{1}H NMR (400 MHz, $CDCl_3$): 9.17 (d, 2H, $J = 2.4$ Hz), 8.75 (m, 3H), 8.51 (d, 2H, $J = 7.2$ Hz), 7.87 (m, 2H). IR (KBr, cm^{-1}): 1699 (s), 1517 (s), 1335 (s). λ_{max} (methanol) 386 nm, $\varepsilon = 10{,}160\ M^{-1}\,cm^{-1}$ and 242 nm, $\varepsilon = 16{,}385\ M^{-1}\,cm^{-1}$. Synthesis of the DMF solvate of 2-(2-amino-4-nitrophenyl)-benzo[*d*,*e*]isoquinoline-1,3-dione (**2**): A mixture of 1,8-naphthalic anhydride (0.990 g, 5 mmol) and 4-nitro 1,2-diaminobenzene (0.765 g, 5 mmol) was refluxed in *N*,*N*-dimethylformamide (10 ml) at 90 °C for 8 h. The reaction mixture was cooled affording crystalline product **2** in 98% yield. ^{1}H NMR (400 MHz, DMSO-d_6): 8.12–8.00 (m, 4H), 7.75 (d, 1H, $J = 2.6$ Hz), 7.67 (dd, 1H, $J = 7.2$, 2.4 Hz), 7.56 (s, 1H), 7.51 (t, 2H, $J = 7$ Hz), 6.54 (s, 2H, NH_2-protons) 6.45 and 6.42 (s, 1H, H–C=O of DMF), 2.50 (s, 3H), 2.34 (s, 3H). IR (KBr, cm^{-1}): 3446 (s), 1740 (s), 1771 (s), 1580 (m), 1304 (s), 1013 (s), 775 (s). The crystallographic parameters of the DMF solvate of **2** and DMSO solvate of **5** are given as Supplementary data.
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